# Probability-Based Estimation of Nearshore Habitat Characteristics

***Allison Bailey, Helen Berry, and Betty Bookheim***
*Washington State Department of Natural Resources, Aquatic Resources Division*

***Don Stevens***
*Dynamac Corporation, USEPA Environmental Research Laboratory*

## Introduction

The loss of nearshore habitat is the most significant threat to the health of marine waters in Puget Sound and Georgia Basin (British Columbia/Washington Marine Science Panel, 1994). Because of the ecological importance of these habitats and the threat of continued habitat loss and degradation, there is a high demand by scientists, managers, and policy makers for information about status and trends in marine and estuarine habitats. Unfortunately, the most recent comprehensive inventory of nearshore habitats in Puget Sound, the Coastal Zone Atlas (Washington State Department of Ecology, 1978), is more than 20 years old.

As part of the Puget Sound Ambient Monitoring Program, the Department of Natural Resources (DNR) Nearshore Habitat Program is developing an updated inventory of intertidal habitats through remote sensing, field verification, and a geographic information system (GIS). The inventory has been completed for Whatcom County (Berry and Ritter, 1997), and areas in Skagit and Island Counties are currently being processed. However, at the current rate and level of resources, a complete inventory of Puget Sound will take at least fifteen years to complete.

In order to fill the information gaps more rapidly, DNR is investigating alternative or supplemental approaches for assessing and monitoring nearshore habitats (Berry et al., this volume). The purpose of this study was to test the utility of a probability-based sampling design for characterizing nearshore habitat status and trends in Puget Sound. The sampling design is based on the designs developed for the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP). The objectives of EMAP are consistent with those of the Puget Sound Ambient Monitoring Program, and include the following (Overton et al., 1990):

- Estimate current status, extent, changes, and trends in indicators of the condition of the nation's ecological resources on a regional basis with known confidence.
- Monitor indicators of pollutant exposure and habitat condition and seek associations between human-induced stresses and ecological condition.
- Provide periodic statistical summaries and interpretive reports on ecological status and trends to resource managers and the public.

This study provides Sound-wide estimates of nearshore habitat distribution and abundance. To facilitate comparison with our inventory, habitats are characterized according to Dethier's (1990) Marine and Estuarine Habitat Classification System and with the same vegetated land-cover classes used for DNR's current mapping program (Berry and Ritter, 1997). In addition, this study estimates the extent of shoreline modification (bulkheads, dikes, fill, etc.) because it is an anthropogenic influence that negatively affects nearshore habitats (Shipman, 1997; Thom et al., 1994). Specifically, the following questions were answered:

1. What proportion of shoreline length has a specific vegetation type, substrate type or shoreline modification?
2. What proportion of intertidal area has a specific vegetation type, substrate type or shoreline modification?

# Methods

## Sample Design

Sample sites for characterizing nearshore habitat were chosen according to the random tessellation stratified design used for EMAP projects. The details of this sample design are beyond the scope of this paper, but detailed descriptions of the design approach and rationale can be found in Stevens (1997), Stevens (1994), Overton and Stehman (1996), and Overton et al. (1990). The design is probability-based and allows estimation of characteristics of continuous spatial populations with known confidence limits. The general approach is to randomly place a hexagonal grid over the area to be sampled and select one point at random from each grid cell. A variation of this approach is used for linear features, such as shorelines and rivers.

For our survey, we randomly selected 325 sites along 3715 km (2303 mi) of shoreline in Puget Sound (Figure 1). Sites were selected with equal probability, and each site represents 11.4 km (7.1 mi) of shoreline. The equiprobable design allows for greater flexibility and simplicity in future analysis, including post-sampling stratification or characterization of sub-populations. For this paper, we stratified the points according to five oceanographically-based basins (Figure 1); however, other spatial strata could be defined for future analyses of the same data set, as long as there are a minimum of 30–40 sample points in each strata.

## Data Collection

Each site was visited in the field to identify the vegetated land cover classes and Dethier (1990) habitat types that were present at that site. The specific classes of interest were:

- vegetation: eelgrass, kelp, green algae, brown algae, red algae, mixed algae, salt marsh, and spit/berm
- substrate: bedrock, boulder, hardpan, cobble, mixed coarse, gravel, sand, mixed fine, mud, organic, artificial

In order to compare this data set with our mapping project, vegetation and substrate classes were assigned according to the predominant characteristics, and a feature had to be at least 1–5 m to be identified as a separate land-cover class or habitat type. (In other words, very narrow bands of vegetation or substrate were generalized into adjacent features).

For the first question, (what proportion of shoreline length has ______?), we identified which vegetation and habitat types were present along a visual transect line, starting at the randomly selected sample site and running perpendicular to the shoreline across the intertidal zone. The focus of the survey was on the intertidal zone, but because of the ecological and policy importance of kelp and eelgrass, subtidal beds of kelp and eelgrass were also documented. The presence of shoreline modification in the intertidal zone and adjacent area was determined after the field survey from a review of the slides of each sample site.

For the second question, (what proportion of intertidal area has ______?), we annotated the transect line and the boundaries of each feature onto an aerial photograph. The across-shore width of the transect and each feature on the transect were measured from the photographs. Across-shore widths of subtidal vegetation (kelp or eelgrass) were not measured and were not included in the areal estimates.

## Data Analysis

Data from this study are analyzed for Puget Sound as a whole, and for five oceanographically based sub-basins, South Puget Sound, Central Puget Sound, Northern Puget Sound (Whidbey Subbasin), Hood Canal, and San Juans and Straits (Figure 1). The number of sample sites and shoreline lengths in each basin are given in Table 1.

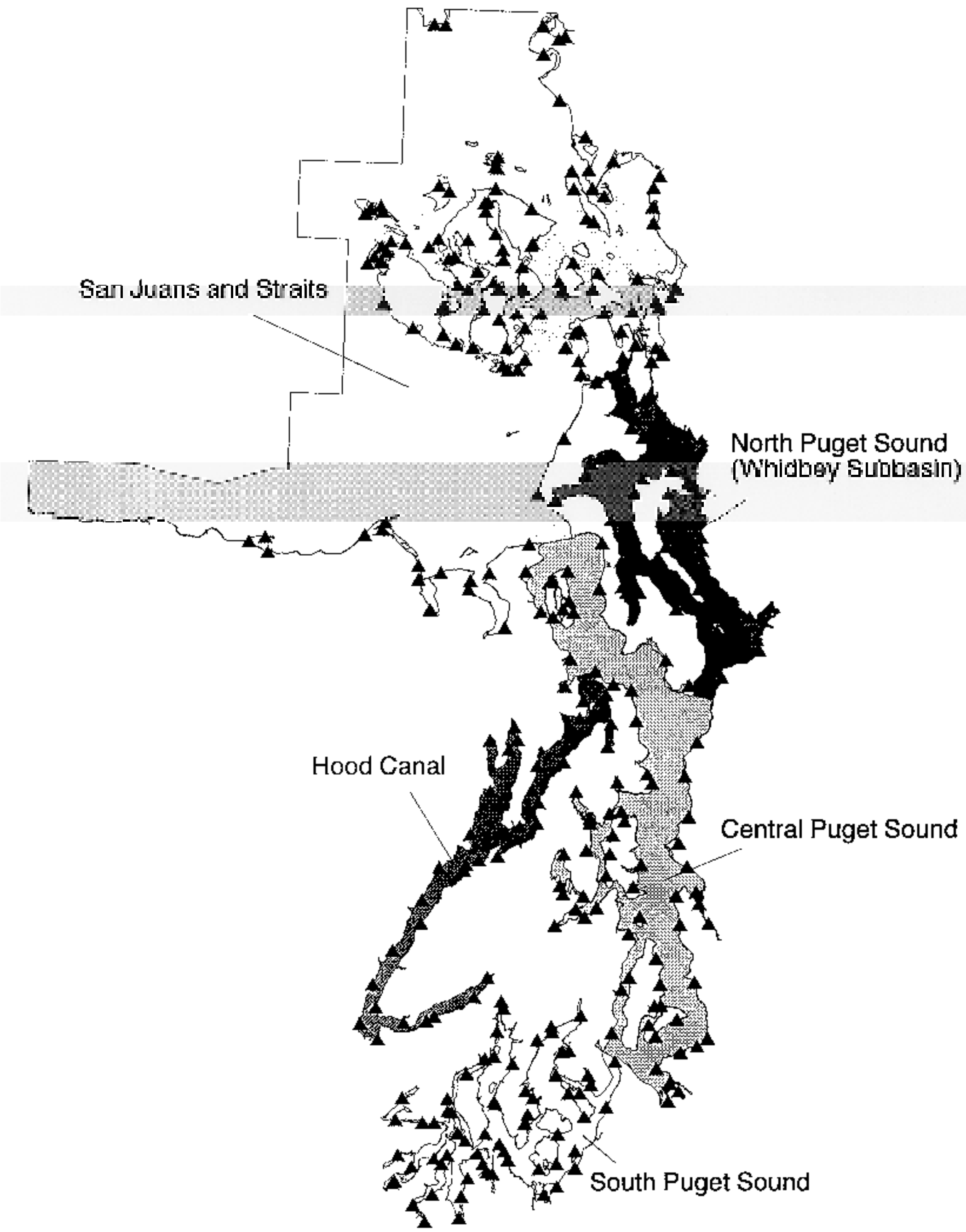


Figure 1. Puget Sound basins and randomly selected habitat survey sites.

Table 1. Number of sample sites and shoreline length by basin.

| Basin | # of Sites | Shoreline Length |
|---|---|---|
| South Puget Sound (SPS) | 64 | 731.5 km (453.5 mi) |
| Central Puget Sound (CPS) | 71 | 811.5 km (503.1 mi) |
| North Puget Sound (NPS) | 42 | 480.0 km (297.6 mi) |
| Hood Canal (HDC) | 34 | 388.6 km (240.9 mi) |
| San Juans and Straits (SJS) | 114 | 1302.9 km (807.8 mi) |
| Total | 325 | 3714.5 km (2303 mi) |

To estimate the proportion of shoreline length occupied by a specific feature (vegetation, substrate, human modification), the number of sites with each characteristic are divided by the total number of sample sites in the basin. Because this is a binomial sample (the feature is either present or absent), and each sample has the same weight (equiprobable), the 95% confidence limits are calculated with standard techniques, using the normal approximation for the distribution (Snedecor and Cochran, 1980).

To estimate the proportion of intertidal area occupied by a specific vegetation or substrate type, we used the Horvitz-Thompson ratio estimator. In an equiprobable design, it is the same as dividing the sum of the across-shore widths of a land cover class by the total across-shore widths (transect lengths) in the basin. The variance is calculated using a simplified form of the Horvitz-Thompson variance estimator (see Stevens, 1997, for general estimating equations), and 95% confidence limits are calculated as above.

Finally, the estimates for proportion of shoreline with kelp, eelgrass, and human modification were compared to existing data sets to assess the accuracy of these estimates, as well as to assess trends.

# Results

## Vegetation

For Puget Sound as a whole, the most common vegetated habitat, as a proportion of shoreline length, is composed of green algae, which cover 28.3% of the shoreline (Table 2). Eelgrass is the second most common vegetated habitat occurring on 23.4% of the total shoreline. The least frequently occurring vegetation type is kelp, which covers only 7.1% of the shoreline length in Puget Sound. The relative frequency of each vegetation type is quite different for each basin. In South Puget Sound (SPS), which has the least amount of total vegetated habitat, salt marsh is the most common vegetated habitat (21.9%). In Hood Canal (HDC), eelgrass is the most common vegetation type (32.4%), and kelp (0.0%) and green algae (5.9%) are the least common. Central Puget Sound (CPS) has the most ‘typical’ pattern of vegetation abundance, with green algae as the most common vegetation type (40.8%), eelgrass as the second most abundant (22.5%), and kelp as the least common vegetation type (2.8%). In Northern Puget Sound (NPS), green algae and eelgrass are equally abundant, each covering 40.5% of the shoreline. Finally, green algae are the most common vegetation in the San Juans and Straits (SJS), covering 29.8% of the shoreline. However, eelgrass and mixed algae are almost as abundant, both covering 27.2% of the shoreline. Spit or berm vegetation is the least common vegetated habitat (10.5%) in the San Juans and Straits. When all vegetation types are considered together, 72.3% of Puget Sound’s shoreline has some vegetated habitat. By basin, the San Juans and Straits have the most vegetation—87.7% of the shoreline length has some vegetated habitat. South Puget Sound is the least vegetated (42.2%). Finally, the confidence limits for these estimates are generally between 3–10%.

Table 2. Estimates of percent of shoreline length with each vegetation type and 95% confidence limits.

| | All PS | | South Puget Sound | | Central Puget Sound | | North Puget Sound | | Hood Canal | | San Juans/ Straits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Vegetation type** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** |
| brown algae | 7.7% | 4.6% | 0.0% | 0.0% | 5.6% | 5.4% | 7.1% | 7.8% | 8.8% | 9.5% | 13.2% | 6.2% |
| green algae | 28.3% | 3.9% | 15.6% | 8.9% | 40.8% | 11.4% | 40.5% | 14.8% | 5.9% | 7.9% | 29.8% | 8.4% |
| kelp | 7.1% | 4.9% | 0.0% | 0.0% | 2.8% | 3.8% | 2.4% | 4.6% | 0.0% | 0.0% | 17.5% | 7.0% |
| mixed algae | 14.8% | 3.9% | 6.3% | 5.9% | 9.9% | 6.9% | 2.4% | 4.6% | 14.7% | 11.9% | 27.2% | 8.2% |
| eelgrass | 23.4% | 2.8% | 1.6% | 3.0% | 22.5% | 9.7% | 40.5% | 14.8% | 32.4% | 15.7% | 27.2% | 8.2% |
| salt marsh | 15.1% | 2.9% | 21.9% | 10.1% | 7.0% | 6.0% | 19.0% | 11.9% | 23.5% | 14.3% | 12.3% | 6.0% |
| spit/berm | 7.7% | 2.9% | 3.1% | 4.3% | 5.6% | 5.4% | 11.9% | 9.8% | 5.9% | 7.9% | 10.5% | 5.6% |
| all vegetation | 72.3% | 4.9% | 42.2% | 12.1% | 69.0% | 10.8% | 81.0% | 11.9% | 73.5% | 14.8% | 87.7% | 6.0% |

The patterns of vegetation abundance are somewhat different when estimated as a percentage of intertidal area (Table 3). From the areal estimates, eelgrass is the most abundant vegetation type for Puget Sound as a whole, covering 19.3% of the intertidal area. Salt marsh is the second most common vegetated habitat (6.8%) and green algae follows (5.3%). The four remaining vegetation types (brown algae, kelp, mixed algae, and spit/berm) cover only 2.7% of the intertidal area of Puget Sound. Areal estimates for each basin indicate that one or two vegetation types are often highly abundant relative to the other types. For example, in the San Juans and Straits, eelgrass covers 42.2% of the intertidal area, whereas none of the other vegetation types cover more than 4.4% of the intertidal area. For Puget Sound as a whole, 33.9% of the intertidal area is covered with vegetation. Similar to the linear estimates, South Puget Sound is the least vegetated basin—only 12.7% of the intertidal area has vegetation. San Juans and Straits have the most intertidal vegetation coverage (53.3%). Confidence limits are generally on the same order as the estimates, ranging from 0.1% to 37.8%.

Table 3. Estimates of percent of intertidal area with each vegetation type and 95% confidence limits.

| | All PS | | South Puget Sound | | Central Puget Sound | | North Puget Sound | | Hood Canal | | San Juans/ Straits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Vegetation type** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** |
| brown algae | 0.5% | 0.3% | 0.0% | 0.0% | 0.5% | 0.7% | 0.3% | 0.4% | 0.6% | 0.9% | 0.7% | 0.7% |
| green algae | 5.3% | 2.2% | 2.1% | 1.9% | 12.0% | 4.4% | 6.8% | 6.2% | 2.2% | 4.4% | 4.4% | 3.7% |
| kelp | 0.2% | 0.1% | 0.0% | 0.0% | 0.2% | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.4% | 0.4% |
| mixed algae | 1.3% | 0.6% | 0.6% | 0.9% | 1.8% | 1.5% | 0.0% | 0.0% | 1.4% | 1.9% | 2.1% | 1.5% |
| eelgrass | 19.3% | 12.3% | 0.2% | 0.4% | 11.4% | 6.6% | 6.5% | 5.8% | 5.4% | 6.3% | 42.2% | 27.2% |
| salt marsh | 6.8% | 4.0% | 9.7% | 14.7% | 2.0% | 3.1% | 9.0% | 9.4% | 18.0% | 8.8% | 2.5% | 2.4% |
| spit/berm | 0.7% | 0.4% | 0.0% | 0.1% | 0.5% | 0.6% | 1.1% | 1.4% | 0.2% | 0.3% | 0.9% | 0.6% |
| vegetation | 33.9% | 14.9% | 12.7% | 15.5% | 28.3% | 10.4% | 23.6% | 8.8% | 27.8% | 22.3% | 53.3% | 37.8% |

## Substrate

The estimates and confidence intervals for the percent of shoreline length and intertidal area with each substrate type are given in Tables 4 and 5. As a percentage of the entire shoreline of Puget Sound, the most abundant substrate types are mixed fine (39.4%), mixed coarse (35.4%), gravel (32.3%), and sand (25.2%). Most Puget Sound basins have a similar pattern of substrate abundances, although Hood Canal has quite a bit more gravel (52.9%) and the San Juans and Straits have a high frequency of bedrock (27.2%) and boulder (18.4%) habitats. Similar to the vegetated habitats, usually two or three substrates comprise the majority of the intertidal area. For all Puget Sound, mixed fine (38.0%), sand (32.2%), and mud (14.8%) are the most common substrates. For the basins, two or three of these same substrates are also the most common substrate types, except for Central Puget Sound where the third most common substrate type is mixed coarse (17.1% of the intertidal area).

Table 4. Estimates of percent of shoreline length with each substrate type and 95% confidence limits.

| | All PS | | South Puget Sound | | Central Puget Sound | | North Puget Sound | | Hood Canal | | San Juans/ Straits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Substrate type** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** |
| artificial | 8.0% | 3.0% | 1.6% | 3.0% | 14.1% | 8.1% | 7.1% | 6.3% | 5.9% | 7.9% | 8.8% | 5.2% |
| bedrock | 12.3% | 3.6% | 1.6% | 3.0% | 2.8% | 3.8% | 9.5% | 7.2% | 5.9% | 7.9% | 27.2% | 8.2% |
| boulder | 7.1% | 2.8% | 0.0% | 0.0% | 0.0% | 0.0% | 2.4% | 3.7% | 2.9% | 5.7% | 18.4% | 7.1% |
| hardpan | 0.6% | 0.9% | 1.6% | 3.0% | 1.4% | 2.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| cobble | 5.2% | 2.4% | 0.0% | 0.0% | 4.2% | 4.7% | 4.8% | 5.2% | 17.6% | 12.8% | 5.3% | 4.1% |
| mixed coarse | 35.4% | 5.2% | 34.4% | 11.6% | 49.3% | 11.6% | 35.7% | 11.7% | 35.3% | 16.1% | 27.2% | 8.2% |
| gravel | 32.3% | 5.1% | 43.8% | 12.2% | 31.0% | 10.8% | 33.3% | 11.5% | 52.9% | 16.8% | 20.2% | 7.4% |
| mixed fine | 39.4% | 5.3% | 56.3% | 12.2% | 31.0% | 10.8% | 31.0% | 11.3% | 35.3% | 16.1% | 39.5% | 9.0% |
| sand | 25.2% | 4.7% | 17.2% | 9.2% | 35.2% | 11.1% | 40.5% | 12.0% | 26.5% | 14.8% | 17.5% | 7.0% |
| mud | 10.8% | 3.4% | 25.0% | 10.6% | 8.5% | 6.5% | 9.5% | 7.2% | 5.9% | 7.9% | 6.1% | 4.4% |
| organic | 1.5% | 1.3% | 1.6% | 3.0% | 0.0% | 0.0% | 2.4% | 3.7% | 2.9% | 5.7% | 1.8% | 2.4% |

Table 5. Estimates of percent of intertidal area with each substrate type and 95% confidence limits.

| | All PS | | South Puget Sound | | Central Puget Sound | | North Puget Sound | | Hood Canal | | San Juans/ Straits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Substrate type** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** | **%** | **conf (±)** |
| artificial | 0.4% | 0.2% | 0.1% | 0.1% | 1.1% | 0.7% | 0.2% | 0.4% | 0.2% | 0.6% | 0.4% | 0.4% |
| bedrock | 1.3% | 0.6% | 0.1% | 0.1% | 0.7% | 1.0% | 0.4% | 0.4% | 0.4% | 0.9% | 2.7% | 1.5% |
| boulder | 0.7% | 0.4% | 0.0% | 0.0% | 0.0% | 0.2% | 0.2% | 0.4% | 0.1% | 0.6% | 1.8% | 1.0% |
| hardpan | 0.0% | 0.1% | 0.1% | 0.1% | 0.2% | 0.4% | 0.0% | 0.2% | 0.0% | 0.5% | 0.0% | 0.4% |
| cobble | 0.5% | 0.3% | 0.0% | 0.0% | 0.4% | 0.6% | 0.4% | 0.6% | 1.8% | 1.6% | 0.4% | 0.6% |
| mixed coarse | 6.2% | 1.2% | 5.7% | 2.6% | 17.1% | 5.7% | 3.7% | 1.9% | 4.4% | 2.6% | 4.3% | 1.7% |
| gravel | 5.5% | 1.4% | 11.1% | 4.9% | 7.5% | 4.3% | 4.7% | 3.7% | 4.4% | 2.5% | 3.2% | 1.6% |
| mixed fine | 38.0% | 19.6% | 22.9% | 16.1% | 28.7% | 21.2% | 25.6% | 18.9% | 18.0% | 18.5% | 61.2% | 49.7% |
| sand | 32.2% | 18.2% | 21.7% | 23.9% | 38.6% | 26.7% | 61.4% | 65.5% | 16.7% | 13.7% | 22.6% | 27.5% |
| mud | 14.8% | 11.3% | 38.3% | 29.3% | 5.8% | 4.7% | 3.0% | 4.6% | 53.4% | 89.3% | 2.6% | 2.9% |
| organic | 0.4% | 0.4% | 0.2% | 0.3% | 0.0% | 0.2% | 0.3% | 0.7% | 0.5% | 1.2% | 0.6% | 0.8% |

## Shoreline Modification

The estimates of percentage of shoreline length with human modification (bulkheads, boat ramps, fill, etc.) Is shown in Table 6. Central Puget Sound has the most modified shoreline (52.1%), and the San Juans and Straits have the least modification (20.2%). 33.2% of all Puget Sound shorelines have been modified or armored.

Table 6. Estimates of percent of shoreline length with human modification and 95% confidence limits.

| | All PS | | South Puget Sound | | Central Puget Sound | | North Puget Sound | | Hood Canal | | San Juans/ Straits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | conf (±) | % | conf (±) | % | conf (±) | % | conf (±) | % | conf (±) | % | conf (_) |
| shoreline modification | 33.2% | 5.1% | 34.4% | 11.6% | 52.1% | 11.6% | 35.7% | 11.7% | 32.4% | 15.7% | 20.2% | 7.4% |

## Comparison with Other Data

The linear estimates of eelgrass, kelp, and shoreline modification were compared to existing inventories to assess the accuracy of the estimates and to look for trends. The eelgrass estimates were compared to eelgrass data from the Coastal Zone Atlas (Washington State Department of Ecology, 1978). The values from the Coastal Zone Atlas (CZA) are within the confidence limits of the DNR estimates, except for Central Puget Sound, where there is more eelgrass in CZA than estimated from DNR's survey, and North Puget Sound, where there is less eelgrass in CZA than found by DNR (Table 7).

Table 7. Comparison of DNR's estimates of percentage of shoreline length with eelgrass to values from Coastal Zone Atlas (CZA) (Washington State Dept. of Ecology, 1978).

| Basin | CZA (1978) | DNR (1995) |
|---|---|---|
| South Puget Sound | 4.3% | 1.6% ±3.0% |
| Central Puget Sound | 34.4% | 22.5% ±9.7% |
| North Puget Sound | 20.1% | 40.5% ±14.8% |
| Hood Canal | 39.1% | 32.4% ±15.7% |
| San Juans & Straits | 21.0% | 27.2% ±8.2% |
| All | 22.4% | 23.4% ± 2.8% |

The linear extent of kelp determined from other data sources (Thom and Hallum, 1991; Washington State Department of Ecology, 1978), is generally within the confidence limits of DNR's probability-based estimates. Based on this series of data there is no clear trend in kelp abundance over time in Puget Sound.

Table 8. Comparison of DNR's estimates of percentage of shoreline length with kelp to values from Rigg, 1912 and Washington Department of Wildlife, 1977 (both in Thom and Hallum, 1991), and Coastal Zone Atlas (CZA) (Washington State Dept. Of Ecology, 1978).

| Basin | Rigg (1912) | WDW (1977) | CZA (1978) | DNR (1995) |
|---|---|---|---|---|
| South Puget Sound | 1.5% | 6.4% | 3.5% | 0.0% ±0.0% |
| Central Puget Sound | 2.4% | 14.1% | 3.9% | 2.8% ±3.8% |
| North Puget Sound | 4.8% | 11.0% | 0.0% | 2.4% ±4.6% |
| Hood Canal | 0.5% | 0.3% | 0.0% | 0.0% ±0.0% |
| San Juans & Straits | 16.3% | 17.3% | 10.1% | 17.5% ±7.0% |
| All | 7.8% | 12.0% | 5.1% | 7.1% ±4.9% |

The estimated linear extent of shoreline modification was compared to data from surveys by Morrison et al. (1993) and Shipman, 1992–1994 (published 1997). The existing surveys are generally within the confidence intervals of the DNR probability-based estimates.

Table 9. Comparison of DNR's estimates of percentage shoreline length with human modification to values from Morrison et al. (1993) and Shipman 1992–1994 (published 1997).

| Basin | Morrison (1993) | Shipman (1992–1994) | DNR (1995) |
|---|---|---|---|
| South Puget Sound | 29% (Thurston Co.) | 25% (Fox Is.) | 34.4% ±11.6% |
| | | 29% (Stretch Is.) | |
| Central Puget Sound | | 49% (Tracyton) | 52.1% ±11.6% |
| | | 59% (Point Monroe) | |
| | | 24% (Brownsville) | |
| North Puget Sound | | 20% (Holmes Harbor) | 35.7% ±11.7% |
| Hood Canal | | | 32.4% ±15.7% |
| San Juans & Straits | | 13% (Birch Point) | 20.2% ±7.4% |
| All | | | 33.2% ±5.1% |

# Discussion

## Characterization of Nearshore Habitats

The probability-based sampling approach used in this study provides estimates of habitat abundance for Puget Sound and general habitat distribution between five subbasins. Because of the demonstrated differences in habitat type and abundance between basins, spatial stratification by subbasin provides critical regional context for many purposes, such as trend analysis, assessment of habitat quality, and setting restoration goals. In addition, estimates of habitat by shoreline length and by intertidal area provide different results; therefore, the measure to be used for a particular purpose should be chosen carefully. Finally, no obvious trends in kelp or eelgrass abundance were seen when comparing this data set to previous inventories. However, these results must be interpreted with caution because different methods were used in each of these inventories.

## Assessment of Probability-Based Sampling Design

The probability-based sampling design has several strengths. First, the accuracy of the probability-based estimates of habitat distribution and abundance is fairly high, as demonstrated by the agreement of these estimates with previously published data sets. Second, the ability to calculate confidence intervals provides a precision for assessing habitat change. Third, although the design is quite complex, the analysis is fairly simple. Finally, the equiprobable design allows for a great deal of flexibility in future analysis; different stratifications or subpopulations (such as, eelgrass vs. no eelgrass) can be defined and analyzed after the data has already been collected.

There are also two main disadvantages of this sampling approach. First, it does not provide site-specific information for specific projects or site assessment. Second, although confidence intervals can be calculated, the precision of these estimates, particularly the areal estimates, may be too low to detect change at the level that is necessary for long-term monitoring.

# Acknowledgments

Many thanks to the people who helped us with field sampling, data analysis, and GIS work for this project—Elizabeth Lanzer, Rebecca Ritter, Paul Salop, Bruce Dahlman, and Mike McDowell.

# References

Berry, H., T.F. Mumford, Jr., G.C. Schoch, and M.N. Dethier. 1998. Mapping shorelines III: management applications for inventory and monitoring. In, Proceedings of Puget Sound Research '98 Conference, March 12–13. Puget Sound Water Quality Action Team, Olympia, WA.

Berry, H., and R. Ritter. 1997. Puget Sound Intertidal Habitat Inventory 1995: Vegetation and Shoreline Characteristics Classification Methods. Report for Washington State Department of Natural Resources, Aquatic Resources Division, Olympia, WA.

British Columbia/Washington Marine Science Panel. 1994. The shared marine waters of British Columbia and Washington: a scientific assessment of current status and future trends in resource abundance and environmental quality in the Strait of Juan de Fuca, Strait of Georgia, and Puget Sound. Report to the British Columbia/Washington Environmental Cooperation Council. Province of British Columbia, Canada.

Dethier, M.N. 1990. A Marine and Estuarine Habitat Classification System for Washington State. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA.

Overton, W.S., and S.T. Stehman. 1996. Desirable characteristics for long-term monitoring of ecological variables. Environmental and Ecological Statistics 3: 349–361.

Overton, W.S., D. White, and D.L. Stevens, Jr. 1990. Design Report for EMAP: Environmental Monitoring and Assessment Program. Report for Environmental Protection Agency. EPA/600/3-91/053. Washington D.C.

Shipman, H. 1997. Shoreline armoring on Puget Sound. Puget Sound Notes 40: 2–6.

Snedecor, G.W., and W.G. Cochran. 1980. Statistical Methods. 7th Ed. Iowa State University Press, Ames, IA.

Stevens, D.L., Jr. 1994. Implementation of a national monitoring program. Journal of Environmental Management 42: 1–29.

Stevens, D.L., Jr. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics 8: 167–195.

Thom, R.M., and L.A. Hallum. 1991. Historical changes in the distribution of tidal marshes, eelgrass meadows, and kelp forests in Puget Sound. pp. 302–313 In Proceedings of Puget Sound Research '91 Conference. Puget Sound Water Quality Authority, Olympia, WA.

Thom, R.M., D.K. Shreffler, and K. Macdonald. 1994. Shoreline Armoring Effects on Coastal Ecology and Biological Resources in Puget Sound, Washington. Coastal Erosion Management Studies, Volume 7. Shorelands and Water Resources Program, Washington Department of Ecology, Olympia, WA.

Washington State Department of Ecology. 1978. Coastal Zone Atlas of Washington. Publication Numbers DOE-77-21-1 through DOE-77-21-12.